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THE SOILS OF THE HIGH PLAINS

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Abstract

The soils of the high plains are mainly alpine humus soils, with lithosols, bog peats and humified peats. There are also smaller occurrences of acid fen peats, acid marsh soils, gley podzols, and snowpatch meadow soils.

The properties of the alpine humus soils, lithosols and bog peats are discussed with special reference to plant-water relations, soil erosion and water yield.

Certain soil properties, and some of the soils themselves, have been developed under conditions which are not active today. It is suggested that recent periglaciation has been an important factor.

Introduction

In comparison with the agricultural and pastoral soils of the State, the soils of the high plains have received little study and are still incompletely understood. Early work described them as being either peaty or shallow and rocky (Prescott 1931), and this impression remained for many years. However, subsequent studies in the Snowy Mountains area revealed a more complex pattern (Costin 1954), which has since been found to exist on the Victorian high plains as well (Costin 1957b). In addition to the peaty and rocky types, there is a variety of organo-mineral soils which are often extensively and deeply developed.

Classification and Distribution of the Soils

Table 1 provides a classification (after Hallsworth and Costin 1950) of the main soil groups recognized on the high plains, together with summarized environmental data.

Of the 8 groups listed, the acid fen peats, acid marsh soils (syn. silty bog soils), snow patch meadow soils, and gley podzols are relatively uncommon, with a combined extent of probably less than 5% of the total area; they will not be considered further here. Attention will be concentrated on the alpine humus soils, lithosols, and bog peats (with associated humified peats) which together cover the remaining 95% or more of the high plains. The relative proportions of these 3 groups, in the order listed, are probably of the order of 20 : 1 : 1, with local variations depending on whether the area concerned is a plateau and hence suitable for the accumulation of bog peat, or steep and dissected and more favourable for lithosol development (cf. Costin 1961: Fig. 2). The main plateau areas are the Bogong High Plains, Buffalo Plateau, the Dargo High Plains, Howitt Plains, the Snowy Plains, the Bennison-Mt Wellington area, and the Baw Baw Plateau. The steeper mountains include the Loch-Hotham-Feathertop area, the arc of mountains from Mt Cobbler to the Bluff, and individual peaks such as Bogong, Buller, Stirling, Gibbo, Pinnibar and the Cobberas (cf. Costin 1957a).

Alpine Humus Soils

The alpine humus soils, the most widespread group, are the climatic climax formation of the high plains. This is evident from their occurrence on all types of

TABLE 1

Soil Groups of the High Plains, and Environmental Data

Soil Group	Distribution and Environment
Organo-mineral soils in which the profile shows no eluviation of sesquioxides; acid to strongly acid throughout:	
Alpine humus soils	Widespread on all rock types and under most physiographic conditions. Vegetation subalpine woodland, sod tussock grassland, heath and tall alpine herbfield.
Mineral soils showing no profile differentiation:	
Lithosols	Locally widespread as current soils in exposed situations and as fossil soils under more sheltered conditions; all rock types, but especially strongly jointed or fractured rocks such as columnar basalt. Vegetation mainly heath; sometimes lacking as on large screes.
Organic soils with high water table, usually near surface level:	
Bog peats	Locally widespread in permanently wet, acid situations, due to springs and seepages on slopes and a high water table along valleys. Bog vegetation.
Acid fen peats	Minor occurrences in permanently wet, level to gently sloping situations, acid but with a small base supply. Fen vegetation, occasionally short alpine herbfield (snowpatch communities).
Humified peats	Locally common in association with drained bog peats.
Organo-mineral or mineral soils with a high water table:	
Acid marsh soils	Minor occurrences, usually associated with acid fen peats, in swampy situations receiving washed-in soil and mineral matter. Fen vegetation, occasionally sod tussock grassland.
Snow patch meadow soils	Restricted to wet, lower snowpatch situations, which continually receive suspended soil and rock material during the snow-melt period. Short alpine herbfield vegetation.
Gley podzols	Locally common in damp situations with an acid water table in the subsoil for most of the year. Vegetation mainly sod tussock grassland, and heath transitional to bog.

topography other than waterlogged and precipitous sites; on parent materials as diverse as granite (e.g. Bogong High Plains), basalt (e.g. Bogong High Plains and Dargo), and sandstone (e.g. the Bluff); and in association with several distinct vegetation types.

PROFILE MORPHOLOGY

The soil profile is of the A-C type, in which the organo-mineral topsoil of good crumb structure, porosity and friability grades through increasingly mineral soil into the more compact parent material beneath, without the development of illuvial horizons of humus, sesquioxides or clay. Textures vary from sands to clay loams, depending on parent material, and become stonier with depth. Floaters usually occur throughout, and in the deeper horizons distinct stone lines and stone layers are often developed. The depth of the profile varies from less than a foot to several feet, but the essential morphological features remain the same. Attention has already been drawn to the generally greater depth of these soils in comparison with soils of many similar mountains overseas, and to the lack of podzolization despite the cool, moist conditions which prevail (Costin 1955). These differences have been related to the milder glacial history of the Australian high plains, their gentler slopes and more favourable soil climate, and to the circulation of soil material by the vigorous growth and decomposition of herbaceous species and by earthworm activity. However, the significanee of these relationships has not yet been critically examined.

Analytical Data

The soils are acid to strongly acid throughout, with pH values of 4-5 in the surface increasing by about half a unit in the subsoil. Typical organie matter contents are 10% in the topsoil decreasing to about 2% in the lowest horizons. In the alpine humus soils developed on gneissic granite in the Kosciusko area (Costin, Hallsworth and Woof 1952), eation exchange capacities are determined mainly by the organic matter: consequently they have moderate values in the topsoil (e.g. 15 m.e./100 g.) but very low values at greater depths (e.g. 5 m.e./100 g.). The exchange capacity is highly base-unsaturated, as would be expected from the high aeidities. However, silica-sesquioxide and free ferrie oxide determinations show no evidence of podzolization. The clays are largely clay biotite, with kaolinite and some free ferric oxide and hydrated aluminium oxide; this composition indicates a relatively slight degree of chemical weathering, a consequence of the cold environment.

Water Relations

Soil properties of importance in plant-water relations inelude those affecting the ability of the soil to absorb, retain, detain and transmit moisture.

In the Kosciusko area, on granitie soils similar to those in granitie areas of the Vietorian high plains, infiltration capacities are greater under moist than dry conditions (Costin, Wimbush and Kerr 1960); this is the reverse of normal experience with less organie soils (Marshall 1959). The most critical conditions as regards surface run-off and soil erosion are therefore thunderstorms during the summer months. On well vegetated soils, infiltration rates after dry spells are of the order of 1″/30 minutes, compared with less than ¾″ on poorly covered soils; the relationships between infiltration and amount of herbaceous cover on a group of otherwise similar plots at Koseiusko is shown in Fig. 1. On the Bogong High Plains Carr and Turner (1958a) have also measured higher infiltration rates on soils with denser vegetation.

Approximate values for bulk density, and available water as determined by the difference in water content between tensions of 100 em and 15 atmospheres are shown in Table 2. These results are for well developed granitic soils at Kosciusko; in shallower stonier soils the available water is rather less.

It will be noted that on a weight basis the organo-mineral horizons contain more available water than the subsoil. On a volume basis, however, which is the more

Table 2

Bulk Density and Available Water of Alpine Humus Soils

Depth (ft)	Bulk Density (gm/cm^3)	Available water	
		gm water/gm soil	In. of water/ft
0-1	0·85	0·27	2·8
1-2	1·30	0·27	4·2
2-3	1·50	0·26	4·7
3-4	1·52	0·21	3·8

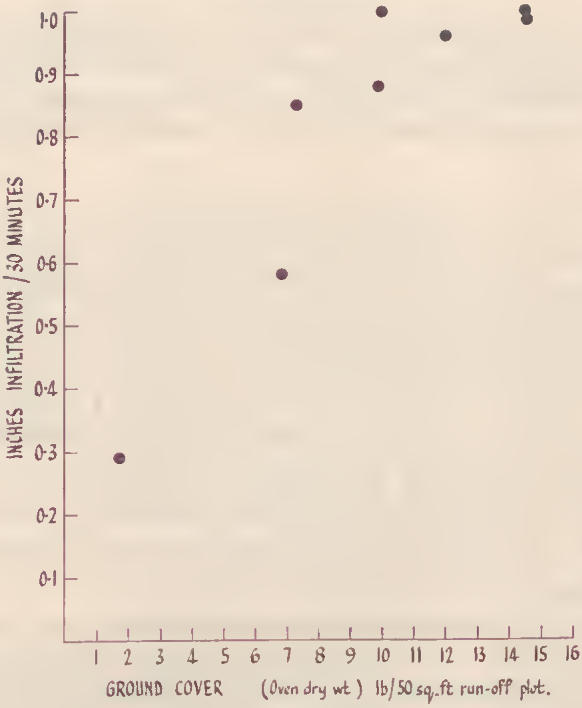

Fig. 1—Relationship between infiltration and amount of cover.

real expression, the surface soil contains least available water. Table 2 can be used to obtain an approximate measure of the water available for any plant or plant community of which the effective root depth is known. For example, minor herbs with most of their root system in the surface foot would have access to about 2·8″ of water, perennial grasses and shrubs with effective root systems down to 2 ft about 7″, and deeper rooting trees at least 10″. Calculations made from soil data of Carr and Turner (1958b) for the Bogong High Plains indicate close agreement with the Kosciusko values; at Bogong the available water in the surface 3″ is about 0·6″ compared with about 0·5″ for Kosciusko.

It is instructive to compare the amounts of available water in Table 2 with evapotranspiration during the snow-free months, calculated on the assumption that maximum values would probably not exceed 75% of the measured evaporation from a free water surface (cf. Penman 1948). Using S.E.C. meterological data for the Bogong High Plains (Carr and Turner 1958a) estimates have been made of average potential evapotranspiration from October to May, and compared with average precipitation for the same period (Table 3).

It will be seen that under average conditions the calculated potential evapotranspiration exceeds precipitation only in January when the atmospheric deficit is 1·6″. Plants are thus unlikely to experience severe water stresses outside this period. Whether such stresses develop will depend largely on the root system of the plant concerned. Reference to Table 2 indicates that most plants with effective root systems a foot or more in depth should have access to sufficient soil moisture during the dry period to maintain evapotranspiration near the potential rate. The available

TABLE 3

Precipitation and Potential Evapotranspiration—Bogong High Plains

Moisture Conditions	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Precipitation	10·07	7·26	5·52	3·92	5·30	5·02	7·97	8·42
Potential Evapotranspiration	2·72	4·25	5·09	5·48	4·28	3·41	1·55	0·66
Difference	7·4	3·0	0·4	—1·6	1·0	1·6	6·4	7·8

water stored within the surface 7″ is about the same as the atmospheric deficit of 1·6″, so that the plants with shallower root systems will undergo temporary and sometimes permanent wilting. Plants with root systems between 6″ and 12″ may occasionally wilt, but only temporarily. However, the rainfall shows considerable variability (Carr and Turner 1958a), so that in drier than average seasons longer periods of water stress can be expected. These predictions are in general agreement with the field observations made by Carr and Turner (1958a).

In somewhat drier environments such as the Bennison-Howitt-Bluff area, potential evapotranspiration may exceed precipitation for at least 2 months. These higher atmospheric deficits, combined with the lower water holding capacity of the soils of this area (mainly Devonian sandstones and shales) are likely to result in depletion of soil water down to 1-2 ft.

The above estimates, which in the Kosciusko area have been confirmed by soil moisture measurements, have important implications for water yield, as well as for plant growth. With the possible exception of the drier high plains areas and stony or sandy soils of very low water holding capacity, water use by different native plant communities should be about the same, since most of the dominant species, whether herbs, shrubs or trees, have root systems which extend down to 2 ft or more. Consequently replacement of one vegetation climax by another is unlikely to materially affect evapotranspiration and water yield. More drastic vegetation changes, such as replacing the dominants by shallow rooting herbs like sorrel or white clover, or destruction of the vegetation altogether, could reduce evapotranspiration by about 2-3″ a year; however, surface run-off and soil loss would be increased (p. 293) and the deposition of snow, rain, cloud and fog would be reduced (Costin 1961).

The permeability of soils to water is important both for plant growth and for water yield. In the case of plant growth, water movement in the unsaturated condition is usually more significant; for water yield, it is movement under saturated conditions. Total porosities of granitic soils in the Kosciusko area vary from about 40-50% of which more than half consist of non-capillary pores. Consequently saturated permeability is likely to be high, and unsaturated permeability relatively low (Marshall 1959). The first prediction is borne out by the observation that during the snow-melt period most of the melt-water percolates rapidly through the soil without the development of perched water tables; at Kosciusko the soil water content in a 6 ft profile decreases from about 35% to 10% in less than two days. The second prediction is supported by the temporary wilting of herbs such as *Craspedia uniflora* Forst. f. during sunny weather although the soil is often moist in the root zone as a whole; presumably the rate of soil water movement under unsaturated conditions is too low to satisfy the local moisture stresses developed at the soil-root interface, until after transpiration ceases at nightfall.

Noteworthy features of soil temperatures are the general lack of freezing, except superficially under certain conditions, and the chilling effects of large volumes of snow-melt water in spring. Although mean air temperatures are below freezing for 1-4 months, the soils as a whole do not freeze because during this period the ground, still relatively warm from summer, is effectively insulated by snow. During the snow-free months, however, when radiation frosts frequently follow warm days, exposed surface soils freeze with the development of needle ice. The source and movement of moisture required for the formation of the ice needles are still obscure. A large part of the moisture seems to be derived from the soil itself, and to move in the vapour stage in response to steep gradients in temperature and vapour pressure between the soil a few inches deep and the air-soil interface. The action of the needle ice is to lift up and loosen the surface soil, and to facilitate its drying out next day, thus leaving it susceptible to wind and water erosion. Another consequence of frost heave is the death of seedlings. By contrast, well vegetated surface soils are insulated against all but the most severe frosts, and effectively resist frost heave.

On the high plains the well-known lag between soil and air temperatures is suddenly evened out during the snow-melt period, when large volumes of water percolate through the soil. During this period soil temperatures are reduced to near freezing point down to depths of several feet. Although this is the period when the soil contains most moisture, trees and shrubs which project above the snow are more likely to undergo wilting than at other times of the year. If strong winds and sunny days accompany the snow-melt period, individual branches of snow gum and occasionally whole trees will wilt and within a few days the leaves begin to turn brown. The critical factor is probably the large increase in the viscosity of water which occurs as it approaches freezing, and the consequent restriction of water movement from soil to root and root to trunk (cf. Handley 1939).

Erosion

It will be apparent from the soil properties described that influences such as fires and grazing which substantially reduce soil cover will increase surface run-off and frost heave and consequently lead to greater erosion by water and wind. Slight to moderate surface erosion of alpine humus soils is now widespread on the high plains, and in some of the highest areas the whole soil mantle is being removed down to an erosion pavement of stones (cf. Costin 1957b). In these areas the inability of the vegetation to prevent complete stripping of the soil, once active erosion has commenced, suggests that the climate has recently become more severe, as postulated in New Zealand (Tussock Grassland Research Committee 1954).

Lithosols

Many steep mountain tops in Victoria, both on the high plains and elsewhere, have extensive rock outcrops on which the formation and accumulation of soil material is minimal. Under these conditions plant roots are largely confined to joint planes and cracks. Such soils are termed skeletal, or lithosols.

Rocky soils of another type also occur on the high plains, sometimes on gentle slopes and in situations which are now relatively protected. These lithosols are generally rather deep and largely consist of angular fragments ranging in size from large boulders to stones a few inches across. The stones in a particular situation are often of more or less similar size, and considerable amounts of finer soil material may occur between them. Drainage is mostly free, in which case the vegetation is heath or only lichens. When the lithosols occur just below springs and seepages, the heath communities usually grade into bog upslope.

These lithosols occur in many forms and sizes, from the huge screes of the Cobungra Valley below Mt Loch and the Valley of the Macalister in the Howitt area, to the widespread moraine-like accumulations of boulders in valleys and along minor streams. Occasionally distinct patterns are developed, in which the individual stones may be sorted into fractions of similar size. The most striking patterns are stone rings or polygons, up to several feet across, seen on gentle slopes of the Bogong High Plains near Mt Jim, on the Dargo High Plains and elsewhere. As the slopes increase the polygons become elongated into more or less parallel stone stripes. Rock rivers or block streams are a similar, but larger development; there are striking examples on the Dargo High Plains (cf. Carr and Costin 1955, Costin 1957c).

Most of the smaller occurrences of lithosols have been largely covered by vegetation, and the larger ones are being colonized from the edges and isolated centres. There is little evidence of active lithosol formation under present conditions, although there is still slight movement on some of the steeper slopes. Few vascular plants can grow successfully under these conditions. On the high plains the prostrate conifer *Podocarpus alpinus* R. Br. is almost unique in this respect. It may be significant that the roots of this pioneer species are nodulated; however, the effectiveness of the nodule organisms has not yet been examined.

The lithosols have very high permeabilities. Those which occur below springs and seepages, and across streams and drainage lines may be effective, therefore, in recharging groundwater and regulating stream flow; if so, they might be used for large-scale water spreading. These possibilities are being examined in the Kosciusko area.

Bog Peats

The bog peats are locally widespread in permanently wet, acid situations. On steeper slopes, where the wetness is localized to springs and seepages, the peat rarely covers more than an acre and often no more than a square chain. Along gentler sloping valley bottoms and on broad cols the peat may be many acres in extent. Depths of up to 10 ft have been recorded (Carr and Turner 1958a) but mostly they are less than 5 ft.

By definition, bog peats contain at least 20% organic matter, part of which is made up of bog mosses, and they are strongly acid in reaction. On the high plains, the average organic matter content down the profile is about 70%, on the basis of Walkley-Black determinations, and pH values are between 4 and 5. The main peat-forming plant is the bog moss, *Sphagnum cristatum* Hpe. with sedges (mainly *Carex guadichaudiana* Kunth.) and several epacridaceous and myrtaceous shrubs.

The profile is rarely uniform from top to bottom. The surface peat is often spongy, yellowish brown in colour, and largely undecomposed. It becomes darker, more compact and decomposed with depth. There is often an irregular alternation of different peat types, and sometimes a rather sudden change in the properties of the peat at some intermediate depth. Most of these features are described below for the profile exposed by the tributary of Middle Cr., above the Rover Hut on the Bogong High Plains:

0–16″—Yellowish brown fairly spongy and porous, largely undecomposed *Sphagnum* peat
16–32″—Yellowish brown, more compact and decomposed *Sphagnum* peat, fairly sharply separated from
32–34″—Brownish, more compact and decomposed *Sphagnum*-sedge peat
34–37″—Yellowish brown, slightly decomposed *Sphagnum* peat
37–39″—Brownish, well decomposed *Sphagnum*-sedge peat
39–42″—Yellowish brown, partly decomposed *Sphagnum* peat

42–44″—Brownish black, partly decomposed *Sphagnum*-sedge peat
44–46″—Brownish, partly decomposed *Sphagnum* peat, sharply separated from
46–51″—Brownish black, greasy, well decomposed sedge peat, resting on
51–60+″—Brownish black gravelly mineral matter.

The above profile is interpreted as showing evidence of a fairly uniform and rapid period of *Sphagnum* development down to 32″, an intermittent and probably longer period of *Sphagnum* development between 32 and 46″, and an early period of fen development below 46″. The 32-46″ stratigraphy can be interpreted in terms of the well-known hollow-hummock pattern of bog development (Tansley 1949), not necessarily autogenic (cf. Walker and Walker 1961), but reflecting variations in external bog conditions of water- or base-supply. The basal layer of fen peat is a usual feature which shows that most of the bogs have developed from an early fen stage. The coarse textured substrate is also common, and frequently consists of large angular stones.

At the present time there seems to be little active peat formation on the high plains. The bog surface consists mainly of shrubs typical of the stillstand and degeneration stages (cf. Tansley 1949, Costin 1954), with few active *Sphagnum* hummocks. The main influences responsible for these conditions are fires and trampling of the bog surface, and drainage due to the entrenchment of gullies and creeks (Costin 1957b). Much of the drying out has occurred within the last 40 years (Carr and Turner 1958a).

Problems of Soil History

As far as possible the properties of soils themselves should provide the evidence for their history and development.

Important features of the alpine humus soils in this regard are their often considerable depth, and their development not only on bedrock but within soil and rock material which shows evidence of earlier mixing and downslope movement. Floaters occur at most levels and often tend to be orientated in the direction of slope; so do the stones of the basal stony layer where this is present. Occasionally lenses of more organic soil occur at depth in what is otherwise largely inorganic material. These soil movements do not seem to be occurring at the present time.

Similarly, the deep lithosols are not forming at present, nor the large patterned features associated with them. The development of these features is thought to require permafrost or deep seasonal freezing of the subsoil, conditions which do not occur on the high plains today (Washburn 1956).

This evidence indicates that periglacial conditions have operated intensively in the past in the development of the deeper lithosols and alpine humus soils. In fact, severe periglaciation is a corollary of the mildness or absence of glaciation on the Victorian high plains. The importance of such periglacial weathering is that subsequent soil formation and plant succession can be very rapid, since deep soil materials of usually favourable mechanical composition are already in existence (cf. Cotton and Te Punga 1955). Further implications are that the high plains provide an excellent hydrological system for the absorption and subsequent discharge of water, but that the risk of accelerated soil erosion is unusually high.

In the absence of absolute age determinations of the stony layers and other reference horizons, it is not possible to say when such periglacial conditions occurred. However, preliminary studies in similar areas of New South Wales and the A.C.T. suggest that periglaciation has been experienced more than once in the recent past. In the Perisher Valley at Kosciusko, a drained peat overlying a basal stony layer which appears to be co-extensive with a stony layer of alpine humus soils in the area, has been dated at 8,100 ± 250 years. Most of the bog peats appear to be younger: the age of the large bog at Ginini (Costin et. al. 1959) is only 3,240 ± 70 years. Like many other currently forming bog peats it rests on a stony base and may indicate a still more recent periglacial phase.

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